



Exploitative and exploratory innovations in knowledge network and collaboration network: A patent analysis in the technological field of nano-energy



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ABSTRACT

Innovations of organizations are doubly embedded in knowledge networks constituted by coupling among knowledge elements and in social networks formed by collaborative relationships among organizations. This study explores the structural properties of such relationships and their possible influences on organizational innovations in terms of exploitation and exploration in the emerging nano-energy field. Results indicate that the knowledge networks and the technology-based collaboration networks in the nano-energy field are decoupled and that they have different degrees of integration. Some structural features of knowledge and collaboration networks influence organizations' exploitative and exploratory innovations in diverse ways. Firstly, direct ties of an organization's knowledge elements in a knowledge network have an inverted U-shaped effect on its exploitative innovation, which is not the case in exploratory innovation. Direct ties in a collaboration network have an inverted U-shaped effect on both its exploitative and exploratory innovations. Secondly, indirect ties of an organization's knowledge elements in a knowledge network affect its exploitative innovation, but not its exploratory innovation. However, indirect ties in a collaboration network affect exploratory innovation, but not exploitative innovation. Thirdly, non-redundancy among ties in a knowledge network exhibits the opposite effect, hindering exploitative innovation, but favoring exploratory innovation. By contrast, non-redundancy among ties in a collaboration network favors exploitative innovation, but shows a non-significant effect on exploratory innovation.

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1. Introduction

Innovation is a collective and social activity. A considerable and fast-growing body of empirical research has shown that innovation by individuals or higher-level collectives (i.e., teams, organizations or countries) is influenced by their social relationships and the networks they constitute by enabling or constraining them to acquire, transfer, absorb, evaluate and apply knowledge and information (Demirkan and Demirkan, 2012; Gonzalez-Brambila et al., 2013; Guan and Zhao, 2013; Guan et al., 2015; Vanhaverbeke et al., 2006). However, in reality, an innovation by individuals or higher-level collectives is embedded not only in social networks but also in knowledge networks (Wang et al., 2014; Yayavaram and Ahuja, 2008). Knowledge elements or components form associational

relationships with one another in innovative processes lead to the formation of a knowledge network in which their past combinatorial relationships are recorded (Phelps et al., 2012; Yayavaram and Ahuja, 2008). Investigation on the critical roles played by both social and knowledge networks needs to be attained a full understanding of the antecedents of innovation performance (Wang et al., 2014). However, to date, few studies have examined the effects of knowledge networks on innovation outcomes of individuals or higher-level collectives, let alone the integration of social and knowledge networks into an analysis framework. Our study is designed to gain further understanding about why and how the relational and structural properties of both social and knowledge networks facilitate and constrain exploitative and explorative innovations of organizations.

Social networks such as technology-based collaboration network or science-based co-authorship reflect the social interactions among a set of agents—individuals, teams, organizations or even countries (Cantner and Rake, 2014; Knoblen et al., 2006; Li et al., 2013; Zaheer and Soda, 2009). These agents form social relationships, such as formal and informal collaborations with each

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other, because they need to bring together diverse resources, knowledge, ideas and information embodied in others who can effectively and efficiently participate in a process that yields innovative outputs (Phelps et al., 2012). These relationships serve as social capital and represent the flowing and searching channels of knowledge and information (Adler and Kwon, 2002; Gonzalez-Brambila et al., 2013; Moran, 2005). These relationships also represent a lens through which social actors can evaluate each other and their knowledge stocks (Phelps et al., 2012). Ongoing debates exist on how social networks facilitate or constrain innovation outcomes of various agents. These debates mainly focus on the structural and relational characteristics of social networks and have been conducted across multiple research fields and multiple levels of analysis (Gonzalez-Brambila et al., 2013; Karamanos, 2012; Phelps et al., 2012; Uzzi and Spiro, 2005). For instance, at the inter-organizational level, sociologists as well as strategy and organizational behavior researchers have investigated how collaboration networks affect innovation outcomes of organizations. The key questions in these studies are whether ego-networks should be sparse or dense, whether organizations should bridge structural holes, or whether ties between organizations should be redundant or non-redundant (Adler and Kwon, 2002; Burt, 1992; Coleman, 1988; McFadyen et al., 2009; Rost, 2011). However, few studies have focused on the effects of this type of network embeddedness on organizations' technological innovation performances in terms of exploration and exploitation.

Knowledge is the core resource of organizations to achieve competitive advantage (Grant, 1996; Moorthy and Polley, 2010). Many scholars have regarded the knowledge base of an organization as a simple aggregation of its knowledge elements. Previous studies mainly focused on how the quantitative characteristics of organizations knowledge base influence their innovation outcomes (Ahuja and Katila, 2001; Boh et al., 2014; Carnabuci and Operti, 2013; Phelps, 2010; Quintana-García and Benavides-Velasco, 2008). Knowledge size, depth and diversity are the important characteristics of organizational knowledge base. The size or breadth of knowledge base of the organization has shown positive effects on its innovation outcomes (Ahuja and Katila, 2001; Boh et al., 2014). Moreover, technological knowledge diversification is found to have a stronger effect on exploratory innovative capability than on exploitative innovative capability (Quintana-García and Benavides-Velasco, 2008). Furthermore, knowledge diversity affects the association between collaborative integration and firms' abilities to innovate by both recombinant reuse and recombination creation (Carnabuci and Operti, 2013; Strumsky et al., 2011).

In contrast to the dominant focus on organizations' knowledge base described above, an epochal study by Yayavaram and Ahuja (2008) examined the structural aspects of organizations' knowledge base. They viewed a firm's knowledge base as a network formed by the coupling relationships among knowledge elements. These relationships record the past combination and affiliation of knowledge elements in the process of innovation, and then serve as the flowing and searching channels for knowledge and guide for future potential combination or recombination of knowledge elements (Phelps et al., 2012; Yayavaram and Ahuja, 2008). The study by Yayavaram and Ahuja (2008) on the worldwide semiconductor industry proved that the level of the knowledge structure decomposability influences invention-related outcomes of organizations. Moreover, Wang et al. (2014) integrated intra-organizational individual collaboration network and knowledge network into a research framework for the first time and found that the structural features of these two networks are distinct and affect individuals' exploratory innovation in different ways through separate mechanisms.

Except for the ground-breaking study by Yayavaram and Ahuja (2008) and Wang et al. (2014), no other systematic study on knowledge network is currently available. Existing studies blur the role of knowledge network embeddedness on innovation, which warrants further research. In contrast to research on simple aggregation of knowledge elements, the structural aspect of knowledge base is promising. Therefore, on the basis of extant research on the effects of social and knowledge networks on innovation, we aim to explore the structural characteristics of knowledge network and inter-organizational technology-based collaboration network in the emerging nano-energy field. We also aim to examine the possible effects of three network features, direct ties, indirect ties and non-redundancy among ties on organizational innovation in terms of exploitation and exploration.

2. Theoretical background and hypotheses

Since March's seminal work on the relationship between exploitation of old certainties and exploration of new possibilities in organization learning (March, 1991), many scholars have investigated exploitative and exploratory innovations (Gilsing and Nooteboom, 2006; Lavie et al., 2010; Quintana-García and Benavides-Velasco, 2008; Wang and Hsu, 2014). Exploitative innovation is characterized by a process of intensive search involving activities along organizations' existing knowledge dimension (Enkel and Gassmann, 2010; Lavie et al., 2010; March, 1991). Therefore, exploitative innovation improves the existing methods or materials used by organizations to achieve their goals. By contrast, exploratory innovation is rooted in an extensive search process pursuing opportunity areas that are new to organizations (Gilsing and Nooteboom, 2006; Lavie et al., 2010; March, 1991). Therefore, exploratory innovation brings in new methods or materials derived from knowledge dimension novel to a given organization (Karamanos, 2012; March, 1991; Wang and Hsu, 2014). In general, exploitative innovation deepens an organization's core knowledge base, whereas exploratory innovation broadens its existing knowledge base. In this study, exploitative and exploratory innovations have specific meanings within the context of technological invention: exploitative innovation means that a focal organization yields intimately familiar technological inventions, whereas exploratory innovation means that a focal organization yields technological novel technological inventions (Vanhaverbeke et al., 2006).

For exploitative and exploratory innovations, technology-based collaboration networks play important roles (Vanhaverbeke et al., 2006). In embedding in this type of network, organizations are given social capital that enables and constrains them to access, search for, transfer and apply related knowledge and information held by other actors in the network in the innovation process (Bierly et al., 2009; Vanhaverbeke et al., 2006). According to the extant studies at the inventor level, knowledge base structure of inventors in an intra-organizational knowledge network implies combinatorial opportunities, potentials and constraints arising from interactions among knowledge elements in past innovations (Wang et al., 2014; Yayavaram and Ahuja, 2008). Innovation builds on the existing knowledge base, and it is also characterized as a combinatorial or recombinatorial process of existing knowledge elements (Fleming, 2001; Schumpeter, 1934), even though we cannot rule out some ideas or inventions emerging with few antecedents (Arthur, 2009; Podolny and Stuart, 1995).

In this study, collaboration networks highlight the importance of social-based search, and knowledge networks highlight the importance of knowledge-based search. Three aspects of both networks probably connect with their benefits and constraints on exploitative and exploratory innovations. (1) First is the number of direct ties maintained by a focal organization in a collaboration network,

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